NASA-CR-195784

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REPORT No. TRC-EM-CAB-9404 6P

ADVANCED ELECTROMAGNETIC METHODS FOR AEROSPACE VEHICLES

Annual Performance Report
(July 1, 1993 - June 30, 1994)

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Grant No.:

NAG1-1082, Supplement No. 4 (MY 1/3)

I. Introduction

The four main topics addressed by the Advanced Electromagnetic Methods for Aerospace Vehicles during this research period are:

a. Antenna Pattern Prediction Methods, Modelings and Computer Codes

b. HF Antennas

c. Composite Materials

d. Antenna Technology

Each of the above topics is briefly addressed, reporting on the progress made and outlining future work to be accomplished.

II. Antenna Pattern Prediction Methods, Modelings, and Computer Codes

An important part of electromagnetic analysis of antennas on helicopter structures is the processing of the helicopter geometry. The geometry processing begins by available cross-sectional data of the helicopter airframe, wings, and horizontal and vertical stabilizers. These cross-sectional data are used to produce graphics representations of the helicopter geometry and provide the input file for the electromagnetics computer codes. Our database of helicopter geometries include:

a. The NASA helicopter model (scale 7:1)

b. The Commanche helicopter model (full size)

c. The Blackhawk helicopter model (full size)

d. The Apache helicopter model (full size)

The geometries for the Blackhawk and Apache helicopter models, respectively, were acquired and processed during this reporting research period.

Most of the work accomplished on antenna pattern predictions was focused on the application of available electromagnetics codes to the analysis of antennas on helicopter platforms. Low- and high- frequency limits of the

a. Numerical Electromagnetics Code (NEC)

b. Electromagnetics Surface Patch (ESP) code

c. Finite-Difference Time-Domain (FDTD) code

d. Finite Element Radiation Model (FERM) code

were recommended and modeling guidelines were provided.

III. HF Antennas

The use of high-frequency (HF) band (2-30 MHz) is one of the primary means of communications available for helicopters. Operationally acceptable antennas such as loops, inverted-L's and monopoles, are very small electrically at the low end of the band. Therefore, they are highly reactive and possess a very low radiation resistance. In addition, in the HF band the helicopter airframe becomes an integral part of the radiating structure. Furthermore, when more than one antenna is used they are expected to operate independently without failure induced by mutual coupling.

Input impedance of HF antennas on helicopters structures was performed using the NEC code. Analysis included:

a. A towel-bar antenna on the surface of the Blackhawk helicopter

b. An inverted-L antenna on the surface of the NASA scaled helicopter

While keeping the size and radius of the antenna fixed, the size and radius of the helicopter mesh were varied in the NEC code to assess their effect on the numerical predictions of the antenna's input impedance. Numerical predictions for the inverted-L antenna on the NASA scaled helicopter were compared with measurements.

Input impedance analysis of a loop antenna on the surface of a square ground plane and a helicopter-like body, was also performed using the FDTD method. The limitations of the FDTD method when calculating wideband electromagnetic characteristics of radiating systems were examined. These limitations are defined by standard "rules of thumb." On the upper frequency range the method is limited by the grid size relative to the wavelength, while on the lower frequency range the method is limited by the accuracy of absorbing boundary conditions and the electrical distance from the structure edges to the outer boundary of the numerical domain.

IV. Composite Materials

The work in the area of composite materials included:

a. Development of three-dimensional volume mesh generator for modeling thick and volumetric dielectrics by using the FDTD method

b. Modeling antenna elements mounted on a composite Commanche tail stabilizer

c. Modification of a geometry subroutine in the FERM code to expedite the modeling process of composite materials

The research in the area of composite materials has been focused on analytic modeling of composite sheets by using a Green's function approach. Some simple composite geometries such as the thin plate, wedge, and square plate grounded monopole have been previously designed to verify the Green's function approach. The surface impedance concept showed encouraging agreement with measurements. Based on this previous work, this technique has been coupled into the NEC code to provide an equivalent surface impedance distribution, which is subsequently used for antenna pattern predictions.

Direct application of the FDTD method relies on the discretization of a complex geometry. In previous research periods, an FDTD surface mesh generator has been developed; however, this was applicable only to objects consisting of conducting surfaces and thin dielectrics. In this period a volumetric FDTD mesh generator has been developed. The volumetric mesh generator allows modeling of thick composite materials. Numerical modeling of a lossy dielectric sphere and a grounded monopole on a thick composite substrate have been demonstrated. The mesh generation has also been applied to a scaled composite Commanche tail stabilizer on which an antenna was mounted.

V. Antenna Technology

The research in the area of antenna technology was focused on the design of:

a. Cavity-backed microstrip patch antennas

b. Ferrite-tuned cavity-backed slot antennas

Such antennas are required to operate in the UHF band (300 - 3000 MHz) or even VHF band (30 - 300 MHz). Operation of such antennas in the UHF or VHF band is limited by the prohibitively large size requirement of conventional antenna designs. One common approach in lowering the operating frequency of the patch antenna is to use a high dielectric substrate. However, this results in heavier antenna designs which are undesirable for aerospace applications.

An alternative way to lower the operating frequency of the patch antenna without substantially increasing the dielectric constant of the substrate is to recess the patch into a cavity. Analysis of scattering and radiation performance of single elements of recessed cavity-backed patch antennas were examined. To achieve bandwidth improvement over the conventional cavity-backed microstrip patch antenna, parasitic elements were added to the antenna structure by stacking its patches.

With the ferrite-loaded cavity-backed slot antenna, theoretical and experimental work, aimed at reducing the antenna operating frequency to UHF band, was performed. The reduction of the operating frequency to the UHF band was accomplished by filling the cavity with ferrite material. The slot antenna can then be tuned over a broad bandwidth by applying different levels of magnetization. Numerical results of the slot antenna gain and tuning capabilities were also examined. The effect of varying the slot position and the level of the DC bias magnetic field on the antenna performance was also examined through a series of experiments. Measurements of the S-parameters of the antenna were obtained and conclusions on the feasibility of such an antenna design were drawn.

ABSTRACTS OF JOURNAL AND CONFERENCE PUBLICATIONS

1. "Automatic and Efficient Surface FDTD Mesh Generation for Analysis of EM Scattering and Radiation," by W. Sun, M. P. Purchine, J. Peng, C. A. Balanis and G. C. Barber, *J. of Electromag. Applicat.*, accepted.

   The first and most important issue in FDTD modeling is to generate a surface mesh of the structure under consideration. There are a few dedicated mesh generators which could discretize the space into cells for general analysis purposes. However, among FDTD applications, a large portion of them deal with objects structured primarily with conducting and/or thin-dielectric plates such as a conducting sphere or cube, a cavity, an airplane, etc.. The mesh data necessary to input are those of node indices and material parameters on the object surface. Geometry modeling is essential to generate FDTD cells on the surface. A simple and effective algorithm capable of on-surface mesh generation is examined based on the ray-tracing method. The algorithm presumes that the input geometry is described by polygons and lines which are often approximations of smooth surfaces and thin wires. In output the algorithm decomposes automatically the polygons and lines into on-surface cells compatible with an FDTD solver.

2. "Vector One-Way Wave Absorbing Boundary Conditions for FEM Applications," by W. Sun and C. A. Balanis, *IEEE Transactions on Antennas and Propagation*, vol. 42, June 1994.

   In this paper a derivation is presented which leads to a new and general class of vector absorbing boundary conditions (ABCs) for use with the finite element method (FEM). The derivation is based on a vector one-way wave equation and a polynomial approximation of the vector radical. It is shown that wide-angle absorbing boundary conditions can be obtained in vector form. Vector plane waves are used to evaluate the accuracy and the reflection performance of these boundary conditions in a wide range of incidence angles. The implementation of the vector ABCs in a FEM formulation is also provided to show how up to the fifth-order absorbing accuracy can be achieved with derivatives only up to the second-order. A possible formulation is described which not only yields a third-order accuracy with first-order derivatives, but also retains the symmetry of the FEM matrix.

3. "Contour Path FDTD Method for Analysis of Pyramidal Horns With Composite Inner E-plane Walls" by P. A. Tirkas and C. A. Balanis, *IEEE Trans. Antennas Propag.*, accepted.

   The contour path finite-difference time-domain (FDTD) method is used for modeling pyramidal horn antennas with or without composite E-plane inner walls. To model the pyramidal horn surface, a locally distorted grid is used. Modified equations are obtained based on the locally distorted grid and the assumptions of the contour path method. The developed algorithm is validated by comparing computed antenna gain patterns, with and without the presence of composite material, with available measurements.

4. "Analysis of Probe-fed Circular Microstrip Patches Backed by Circular Cavities," by J. T. Aberle and F. Zavosh, *Electromagnetics*, 14:239-258, 1994.

   In this article, a full-wave moment method solution for probe-fed circular microstrip patch antennas backed by circular cavities is presented. The antenna performance in both scattering and radiation cases are considered. Results are compared to those of conventional probe-fed circular patch antennas.

5. "Infinite Phased Arrays of Cavity-Backed Patches," by F. Zavosh and J. T. Aberle, *IEEE Trans. Antennas Propag.*, Vol. 42, No. 3, March 1994.

   An analysis of the radiation properties of infinite phased arrays of probe-fed circular microstrip patches backed by circular cavities using a rigorous Green's function/Galerkin's method is presented. The effect of substrate thickness on both scan volume and bandwidth performance is considered. Results are compared to those of infinite arrays of conventional probe-fed circular patch antennas.

6. "Finite-Difference Time-Domain of HF Antennas" by W. V. Andrew, C. A. Balanis, C. Birtcher and P. A. Tirkas, *IEEE Trans. Antennas Propag. Society Intern. Symp.*, Seattle, WA, June 1994, accepted.

   In this investigation, the FDTD method has been applied to low frequency or electrically small radiating structures. The recent development of higher-order absorbing boundary conditions (ABC) has allowed the use of very small cell sizes in the FDTD computational space by placing the absorbing boundaries closer than the traditional one wavelength from the scatterer or radiating structure. The FDTD method with higher-order absorbing boundary conditions was used to model and predict the far-field radiation of electrically short antennas. Results are presented and compared with measurement for HF loop or "towel bar" and inverted-L antenna elements used at 10 MHz mounted on a helicopter-like body, a square cylinder. The computed radiation patterns compare well with measurements.

7. "Radar Cross Section of a Ferrite Tuned Cavity Backed Slot" by D. M. Kokotoff, B. El-Sharawy and J. T. Aberle, *IEEE Trans. Antennas Propag. Society Intern. Symp.*, Seattle, WA, June 1994, accepted.

   The cavity backed slot (CBS) antenna is an attractive candidate for aerospace applications due to its lightweight, low profile, and conformal attributes. However, conventional CBS antennas are usually limited to UHF and higher frequencies due to size constraints. The antenna size can be reduced by loading the cavity. Unfortunately, cavity loading reduces the antenna's bandwidth and increases its weight. An alternative approach is to load the cavity with ferrite. Besides reducing the size of the antenna, the material properties can be varied with the application of an external bias field. The antenna comprises an aperture in an infinite ground plane backed by a cavity which is filled with various ferrite and dielectric layers. The structure is tuned by varying a DC magnetic bias field in the plane of the layers. The antenna is analyzed using the method of moments wherein the Green's functions are formulated using the spectral domain transmission matrix approach. By examining the scattering response of the antenna, one may determine resonant frequencies and qualitatively assess the antenna behavior. Dynamic, as well as, magnetostatic volume and surface wave mode resonances were examined.

SEMIANNUAL AND QUARTERLY PROGRESS REPORTS

1. Report No. TRC-EM-CAB-9401 entitled "Advanced Electromagnetic Methods for Aerospace Vehicles," by C. A. Balanis, W. Sun, *et al.*, Semiannual Progress Report, (July 1 - December 31, 1993), Grant No. NAG-1-1082 (AHE), NASA Langley Research Center, Hampton, VA.

2. Report No. TRC-EM-CAB-9403 entitled "Advanced Electromagnetic Methods for Helicopter Applications," by C. A. Balanis, P. A. Tirkas, *et al.*, Quarterly Progress Report, (January 1 - March 31, 1994), AHE Program.